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the human factors problem associated with [redacted]rity of Army systems (e.g., unintentional compromise, security relevant error, intentional insider attack). R[redacted]rch is encouraged in the area of measures and metrics associated with assurance determination of existing sy[redacted]s (particularly when the existing security perimeter has been modified operationally) and for the security[redacted]ineering process associated with new development (which includes new code and COTS composition). Means [redacted]atching the security protection mechanisms to the existing threat and modifying this set of factors as the thre[redacted]anges are sought. Research into processes and procedures that minimize human error and vulnerability int[redacted]ction is encouraged.

5.5.3.2. *Testing, Assessing, and Mitigating* [redacted]*m Vulnerabilities.* The objective of this research strategy is to develop the technology necessary to test, as[redacted], and minimize system vulnerabilities, particularly in the Objective Force environment. This environment will [redacted]ist of technologies not yet established, such as dynamic, wireless networks. Nevertheless, it is essential that t[redacted]g, assessment, and risk mitigating technologies be researched *a-priori* so that as these new technologies em[redacted], the capability will exist to test and assess the security of these systems. This will certainly include finding[redacted]v vulnerabilities of existing technologies, developing new security attacks and attack countermeasures, and ada[redacted]e risk mitigating technologies. These testing, assessment, and risk mitigating techniques must be adaptable to [redacted]ew technologies as they emerge. Research concentration areas include: (1) System security and vulnerabili[redacted]ssessment framework and methodology, (2) Novel security and vulnerability assessment methods, (3) Adap[redacted] countermeasures to attacks and to system vulnerability exploitation, and (4) Framework and methodology for bu[redacted]g secure, intrusion immune host and network systems.

5.5.3.3. *Correlation, Fusion, Analysis, and* [redacted]*ualization of Systems Security Information.* The objectives are to (1) develop techniques and a quantita[redacted] basis for the correlation, fusion, and analysis of multi-source infrastructure protection data to relia[redacted]and adaptively provide attack indications and warning, and (2) develop a scalable, modular, and open v[redacted]lization and analysis environment that correlates, aggregates, prioritizes, and displays situatio[redacted]areness data from multiple sources in a way that significantly increases the ability of an anal[redacted]o recognize and react to incidents. Research concentration areas include: (1) Multi-Sensor, Multi-Site [redacted]t Correlation, Analysis, and Fusion, (2) Methodology and techniques to improve the quality of attack [redacted]cations or warnings, and (3) Visualization and Presentation.

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RESEARCH AREA 6
PHYSICS

6.0. The objective of the Physics Program of the Army Research Office is to develop and exploit the physics knowledge base for new Army needs and capabilities. The future promises dramatic changes in military capability as a result of physics research. In support of this goal, the interests of the Physics Division are primarily in the following areas: Condensed Matter Physics; Theoretical Physics and Nonlinear Dynamics; Quantum Information Science; Atomic and Molecular Physics; and Optics, Photonics, and Image Science. Physics disciplines which impact these areas include: (i) Condensed Matter Physics, (ii) Interface/Surface Physics, (iii) Atomic, Molecular, and Optical Physics, (iv) Materials Physics, (v) Cross-Disciplinary topics, and (vi) Classical Phenomenology. There is little direct interest in Relativity and Gravity Physics, Elementary Particles and Fields Physics, Nuclear Physics, Astronomy, and Astrophysics since they generally have no impact on the research areas of Army needs. Nevertheless, the possible relevance of topics within these other physics disciplines is not absolutely discounted and discussions of potential exceptions are welcome.

The disciplinary boundaries of the ARO are not sharply drawn as shown by the joint support of a number of efforts by the Physics Division and other ARO Divisions. In addition, it is not necessary that a potential chief investigator be associated with a Physics Department to receive support from the Physics Division.

Potential offerors are encouraged to contact the appropriate Technical Point of Contact (TPOC) for preliminary discussions on their ideas. The TPOC may invite the offeror to submit a preproposal.

6.1. Condensed Matter Physics. The properties of novel inorganic, organic, hybrid materials and composites are determined by the structure and composition of the constituent materials and the modified physical phenomenology within them. The condensed matter physics thrust investigates and exploits such phenomena to demonstrate new or enhanced functionalities that could be exploited for use by the Army. There are four major areas of interest within the condensed matter physics work package.

6.1.1 Nanometer-scale physics. Specific interest is in the experimental investigation of physical phenomena operative in nanometer-sized materials. The objective is twofold: to investigate and control nanoscale phenomena in well-defined nanometer-sized environments and to elucidate how these phenomena are modified and may be exploited when such nanostructures are assembled into novel composite materials. Related interests include collective and cooperative nanoscale phenomena, understanding the evolution of atomic to nanoscale to bulk behavior and phenomena at surfaces and interfaces such as film growth, Fermi-level pinning and quantum confinement effects. Emphasis of this program is on the demonstration of revolutionary capabilities that could be used in a broad variety of Army-relevant applications, including novel optical and infrared materials and innovative electronic and optoelectronic devices.

6.1.2. Electronic and Photonic Band Engineering. Interest continues in the use of electronic band engineering for the demonstration of militarily relevant device functionalities such as infrared emitters based on quantum cascade lasers and lasing without inversion in multiple quantum well semiconductors. Of greater interest is the continuing development and use of photonic band engineered materials for applications including novel microcavity lasers and LEDs, room temperature infrared sensors, enhanced microwave components, and low emissivity materials. The objective is to use electronic and photonic band engineering independently and together as adjustable design degrees of freedom to develop devices and materials with unique functionality. Methods of solving the inverse problem, finding optimal material and structural parameters based on prescribed functionality, are of particular interest. Applications include infrared emitters and detectors, low observables, and micro photonics for smart sensors.

6.1.3. Soft Condensed Matter Physics. Interest is in understanding the physical basis for structural, electronic, and optical properties of bulk, thin film, and nanoscale soft materials such as organic semiconductors, composites, and biological materials. Also of interest is the physical understanding of the interface between soft materials and inorganics, and between soft materials and nanostructures such as carbon nanotubes and nanoclusters. Although there is some interest in revolutionary synthetic techniques, the primary objective is to understand the underlying physical properties of soft materials at the quantum level. This will support the development of applications relevant to the Army including but not limited to flexible electronics, novel organic-based electronic and optical devices, and biocompatible devices.

6.1.4. Multifunctional Probes and Control. In order to characterize and control phenomena in semiconductor heterostructures and nanostructures, it is important to combine the high spatial resolution of nanoprobes with the ultra fast temporal or adjustable spectral resolution of optical probes. The objective is to observe and control the dynamical evolution of physical phenomena in these materials at all relevant length- and time-scales. Although development of nanometer-scale pump-probe techniques and other probes of local behavior is still sought, the exploitation of such tools to demonstrate feedback and control of phenomena is of increasing interest.

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6.2. Theoretical Physics and Nonlinear Phenomena. The Theoretical Physics and Nonlinear Phenomena program is very closely coupled to experimental science as well as to ARO's programs in mathematics, chemistry, biological chemistry, materials science, and engineering sciences. The program thus encompasses a broad base including research in electron physics, photon physics, classical and quantum mechanical systems, and statistical physics. It includes first-principles derivations of thermomechanical strengths of alloys for armor and armor penetrations; electronic band structure calculations of materials for electronic, magnetic, optical, and optoelectronics applications, including those that result from quantum well and multiquantum well structures for signal generation, signal processing, propagation and detection of signals. Also of interest are many-body theoretic approaches that address the electron correlation problem in extended molecular and condensed matter systems to provide the means to predict reaction kinetics, nonequilibrium dynamics, and application to the "alloy problem." There is interest in quantum optics research to explore the role of coherent states, squeezed states, etc. which may provide new tools for improved information processing and means to control information. Statistical physics interests go beyond thermodynamics, into non-equilibrium structures and their metastability, into information theoretic formulations, and into decision algorithms to connect the underlying physics to real world applications via proper modeling, instrumentation and data analysis.

6.2.1. Theoretical Condensed Matter Physics. The program extends beyond the topical areas of conventional solid-state physics. It includes research in liquid crystals (for displays, information processing, etc.), atomic clusters, quantum well structures, superlattices, and metastable structures such as quasi crystals and alloys. It explores fundamental interactions such as electron-phonon coupling, spin-phonon coupling, and polaritons. In addition, it studies the role of elementary interactions such as spin-waves in ferrites and plasmons in multiquantum wells for coherent THz radiation generation. Also of interest are the experimental demonstrations and mathematical underpinnings of enhanced retro reflection and super-enhanced retro reflection of light, which may have unique applications for secure light-wave communication in the battlefield. Another area of interest is the study of "cooperative behavior" which appears in many different forms in solid-state physics, optics, and elsewhere. The program encompasses research in both classical and quantum domains, from macroscopic (phenomenological/mean field) to microscopic levels of description of the mechanisms involved. In addition to analytical techniques, it includes the development of new computational methodologies. For example, the use of the principle of maximum entropy, functional integral methods in many-body physics for predicting electron dynamics in quantum well structures, and variants of the density functional method.

6.2.2. Nonlinear Dynamics. Nonlinear interactions that are useful for Army applications appear not only in optics but in other parts of physics, such as in magnetism in the form of magnetostatic solitonic waves for millimeter wave signal processing, in semiconductor multi-quantum well plasmas for generating coherent THz radiation, and in general when an interaction potential significantly deviates from a harmonic form. Defects, both unintentional and intentional, can play major roles. A general theory of "band structure" calculation that takes defects and defect structures correctly and accurately into account will be useful not only for semiconductor science but also for optics and even micromechanics. Many of the elementary excitations of solid-state physics could be investigated in light of information processing to increase S/N, density of information and speed of processing. The Theoretical Physics program makes an effort to develop these potentialities vis a vis realistic materials that can embody them, and thereby transition these studies to the Materials Science and Engineering Sciences Divisions for actual implementation.

6.2.3. Nonequilibrium Dynamics. Many aspects of the field of nonequilibrium statistical physics have significant unresolved scientific issues. These issues are not just of academic interest; they impact engineering sciences, from growth of new materials to implementations in neural nets, and also have potential implications for what is dubbed "smart" or "intelligent" systems that have adaptive learning capabilities. This is a vast area of investigation, but our Theoretical Physics program focuses on realistic goals in this area. The physics to be studied should be coupled with actual material mechanisms. In magnetism, this may translate into the study of the coupling of spins to phonons to provide a realistic relaxation mechanism and the associated resonant line widths. We are interested in magnetic superlattice type structures which can respond to mm waves by forming magnetostatic and magnetooptic waves that have sufficiently long lifetime and propagation distance for signal processing functions. Also, significant theoretical contributions can be made to the science of alloys, via a quantum mechanical calculation of the characteristics of the bonding charge between nearby atomic constituents. This would provide some guidance to "engineer" grain boundaries with specific brittle fracture characteristics needed for Army and civilian applications.

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6.3. Quantum Information Science. Quantum mechanics provides the opportunity to perform highly nonclassical operations that can result in exponential speed-ups in computation or ultra-secure transmittal of information. This work package seeks to understand, control, and exploit such nonclassical phenomena for revolutionary advances in computation and secure communication. There are three major areas of interest within this work package.

6.3.1. Fundamental Studies. Experimental investigations of the wave nature of matter, including coherence properties, decoherence mechanisms, decoherence mitigation, entanglement, nondestructive measurement, complex quantum state manipulation, and quantum feedback are of interest. The objective is to ascertain the limits of our ability to create, control, and utilize quantum information in multiple quantum entities in the presence of noise. Of particular interest is the demonstration of the ability to manipulate quantum coherent states on time scales much faster than the decoherence time, especially in condensed matter systems where scalability to many quantum bits and quantum operations is promising. Theoretical analyses of nonclassical phenomena may also be of interest if the work is strongly coupled to a specific experimental investigation, e.q. proof-of-concept demonstrations in atomic, molecular, and optical systems as described in the Atomic, Molecular, and Optical Physics program.

6.3.2. Quantum Computation. Quantum computing will entail the assembly and manipulation of hundreds of quantum bits. The objective is to demonstrate tremendous speed up of computations, and experimental demonstrations of quantum logic performed on several quantum bits operating simultaneously would represent a significant advance toward that ultimate goal. Demonstrations of quantum feedback and error correction for multiple quantum bit systems are also of interest. In addition to the algorithm for factoring, there is particular interest in developing algorithms for solving an NP-complete problem for use in resource optimization and in developing quantum algorithms to simulate complex physical systems.

6.3.3. Quantum Communication. The ability to transmit information through quantum entanglement distributed between spatially separated quantum entities has opened the possibility for an ultra-secure means of communication. Beyond quantum cryptography, the objective is to demonstrate quantum communication of information based on distributed entanglements such as in quantum teleportation. Of particular interest would be the demonstration of long-range quantum entanglements, entanglement transfer among different quantum systems, and long-term quantum memory.

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6.4. Atomic and Molecular (AM) Physics. Research in atomic and molecular physics will create fundamentally new capabilities for the Army, as well as providing the scientific underpinnings to enhance existing technologies. Topics of interest include laser, evaporative, and novel cooling and trapping schemes; quantum degenerate atomic gasses, their excitations and properties, including mixed species, mixed state, and molecular; matter-wave optics and matter wave lasers; nonlinear atomic and molecular processes; quantum control; novel forms and effects of coherence; and related areas. Applications range from ultra-sensitive detectors including improved inertial sensors and navigation aides; to sensor protection; to novel sources. In addition, areas of application include novel materials processing, e.g., by obtaining increasingly complex molecules, clusters, or patterned structures, as hybrid or composite materials, or through quantum control.

6.4.1. Matter-wave Optics. Matter waves offer new or enhanced capabilities in a number of areas. For example, cooling, trapping and coherent control of atoms and molecules may provide ultra-sensitive sensors, including gyroscopes for inertial navigation, or ultra-high resolution lithography. In addition to the sensitivity advantage of matter waves, they also have additional degrees of freedom such as mass and associated “external” quantum states (together with a richer internal state structure) that might provide handles for new sensing capabilities. The use of coherent matter waves and Bose condensates (e.g., as in a “matter-wave laser”) requires basic research to better understand issues such a coherence and decoherence, trapping and out-coupling techniques, and “matter-wave optics” to collimate, diffract, split, combine, interfere and otherwise manipulate matter waves. Laser cooling and trapping of atoms and molecules also may provide proof of principle demonstrations of key components of quantum computing.

6.4.2. Molecular Physics. The molecular physics program is distinguished from programs in chemistry and in materials science. One distinguishing feature is its focus not on synthesis, but on the underlying *mechanisms*, such as electronic transport, magnetic response, coherence properties (or their use in molecule formation/selection), and/or linear and nonlinear optical properties. The systems of interest are well-defined molecules, generally small or of high symmetry, and their functionalized variants. The objective is to broaden the scope of atomic physics questions into the molecular regime. Cooling, trapping, and Bose condensing molecules fall into this scope. Recently seen coherent molecular superposition states, a novel form of matter, are another example.

6.4.3. Fundamental Atomic and Molecular Physics. The Division also has a general interest in exploring fundamental atomic and molecular physics topics that may have an impact on technologies of interest to the Army. For example electromagnetically induced transparency allows propagation of light through a medium that is normally strongly absorbing, and it also provides unique access to nonlinear effects that could lead to very efficient frequency multiplication and tunable sources of electromagnetic radiation. The understanding of the physical mechanisms behind long range, white light propagation of ultra-short, ultra-intense pulses is another example of a topic of interest with unresolved atomic and molecular physics issues. General issues of quantum coherence, quantum interference, and quantum control and their numerous potential applications are also of interest.

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6.5. Optics, Photonics, and Imaging Science. The Army of the 21st century will rely more on sensing, imaging processing, and autonomous target tracking and recognition than ever before. The objective of this work package is to investigate fundamental physical phenomena that will lead to revolutionary advances in these areas. The Physics Division emphasizes fundamental science that uses photons and their properties (e.g. coherence, wavelength, polarization) in ways that will significantly improve information processing capabilities for the Army in the coming decades. Much like the breakthroughs in integrated electronics that brought revolutionary changes to computing and signal processing, a key objective is to integrate elemental optical components into "integrated optics" or "photonics" for smart, adaptive, reconfigurable sensing and image processing. Another objective is to improve the imaging capabilities of the Army by extending beyond the visible and infrared regions to consider advantages of the THz and ultraviolet regions. The Division has an interest in the identification and resolution of basic research issues that would demonstrate the utility of these approaches.

6.5.1. Unconventional Optics and Imaging. The Division has an interest in extracting more information from emitted, scattered, and reflected electromagnetic radiation. Of particular interest is the exploitation of coherence and correlations in the electromagnetic field. The degree of coherence can affect or improve the ability to image objects, transfer information, and recognize targets. When a laser beam passes through a scattering medium, the degree of coherence is altered depending on the amount of randomness and the scattering processes involved. Multiple scattering and partial coherence depend on both volume effects and scattering from many interfaces. A number of such physical effects have been observed and explained, but many issues need investigation. Other areas of interest include hybrid optical/digital systems to minimize aberrations in classical optics, adaptive optics to mitigate against atmospheric distortions, new approaches to coherent or ballistic imaging through turbid and scattering media, and imaging enhancement technologies such as hyperspectral imaging, infrared polarimetric imaging, and THz imaging. Also of interest are other approaches that would increase the resolution or contrast of scenes, or otherwise improve the information quality of the images in the presence of noise and clutter.

6.5.2. Fundamental Optical Physics. A variety of topics in classical, nonlinear, and quantum optics are of interest. Photonic band engineering may be used to control the flow of light in fiber, optical materials, laser resonators, and integrated optical systems much more efficiently and compactly than today's component-based technologies. Investigations and utilization of novel nonlinear optical phenomena, such as solitons, vortices, and left handed materials, are of interest and show potential for optical information processing. Relativistic, extremely short and high intensity laser pulses show potential for a new frontier in optical physics, with applications including high harmonic generation, nanolithography, 3-D internal design, micromachining, particle beam acceleration and control, and light filaments. Theoretical and experimental research is needed to describe and understand how matter behaves under these conditions, from single particle motion to the effects in materials, and how to generate these pulses and use them effectively.

6.5.3. Photonics. The word "photonics" has been used in a broad sense by the optical science community to define the development of photon-based devices and circuits to perform certain imaging and information processing tasks in a manner superior to or impossible by their electronic counterparts. The Physics Division seeks revolutionary changes in ways photons can be used to perform a variety of such tasks, including signal processing, computation, imaging, and information display. Of particular interest are unique, niche applications for photonics that surpass or replace their electronically based counterparts and that are of direct relevance to the needs of the military. Any super parallelism promised by photonics needs to be demonstrated and exploited in order for photonic solutions to replace existing electronic ones. It is clear that the field of photonics is a very rich frontier for physics research with high potential for device and system technologies. Therefore, the emphasis of this work package is to explore the basic physics and to demonstrate proof-of-concept demonstrations that will ultimately find indispensable military and civilian application.

6.5.4. Image Science. The ubiquitous presence, especially in Army scenarios, of structured or target- like clutter is a major impediment to all target recognition systems, including both automatic systems and humans. In many Army scenarios and systems, the performance of image analysis systems is limited by the algorithms, signal processing strategies and models, rather than the sensors or processors. Even though there has been a large investment in automatic target recognition algorithms, significant shortcomings exist, leading to the need for a renewed emphasis on the theoretical underpinnings. To this end, the Division is interested in innovative research which addresses the following objectives: (i) development of a set of scientific metrics which quantify image content, image complexity, and the performance of image recognition and classification techniques, (ii) development of metrics for structured and target-like clutter, (iii) development of metrics for assessing and validating synthetic scenes. The ultimate goal is to develop image science to the point that the performance of automatic target recognition systems in arbitrary real-world scenarios can be predicted. The emphasis of the Image Science program is on the underlying issues of information science and image analysis. Other ARO programs are concerned with the development of the detectors and algorithms themselves.

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RESEARCH AREA 7
CHEMISTRY

7.0. Chemistry is central to the operation of the Army Research Office. Explosives, propellants, fuel cells, and batteries function by converting chemical energy into mechanical and electrical energy. Macromolecules, especially elastomers, provide materials for equipment. Protection of the soldier against chemical agents requires the detection, identification, and destruction of such chemicals, and the design and construction of barriers to their passage. The destruction of toxic wastes represents another chemical problem faced in the restoration of military real estate and the safe demilitarization of surplus munitions. We invite proposals for research to advance our understanding of chemical materials and processes with a strong prospect for use in future Army technology.

Potential offerors are encouraged to contact the appropriate Technical Point of Contact (TPOC) for preliminary discussions on their ideas. The TPOC may invite the offeror to submit a preproposal.

7.1. Chemical Kinetics. The Army's program in ignition and combustion processes associated with energetic materials, explosives, detonation phenomena, the control of energy release and energy transfer processes will benefit from increase understanding of fast reactions of energetic species. We are especially interested in the investigation of chemical reactions using time-resolved techniques to observe transient species and infer reaction pathways and other experiments and calculations that enable modeling of the time dependent processes of ignition and combustion. Research on controlled transformation of toxic materials to relatively benign products in chemical reactors is also of interest.

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7.2. Electrochemistry and Advanced Energy Conversion. The Army relies on compact power sources to support many different weapons systems, communications, and other devices. Power sources under development include batteries and fuel cells, microturbines, thermophotovoltaics, alkali metal thermal to electric converters. This program supports fundamental chemical studies of materials and processes that limit the performance of current or enable future power sources. Topics include ionic conduction in electrolytes, electro catalysis, fuel processing (particularly hydrogen), interfacial electron transfer, transport through coatings, surface films and polymer electrolytes, and activation of carbon-hydrogen bonds. Novel electrochemical synthesis, investigations into the effect of microenvironment on chemical reactivity, and quantitative models of electrochemical systems are also encouraged.

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7.3. Organic Chemistry and Organized Media. There exists a need for basic research in detection of toxic materials, decontamination of those materials, and protection of the soldier during those processes. This program seeks to explore fundamental research addressed at eliminating toxic materials in processing and protect the soldier from